Agriculture and Ecosystem Restoration in South Florida: Assessing Trade-Offs from Water-Retention Development in the Everglades Agricultural Area

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Agricultural production decisions can affect ecosystem function and environmental quality. Environmental restoration policies can, in turn, affect the profitability of the agricultural sector. A dynamic model of agricultural production, soil loss, and water retention in the Everglades Agricultural Area is developed to assess agricultural impacts under alternative water policy and land acquisition scenarios.

Key words: ecosystem management, Everglades Agricultural Area, soil subsidence, water retention, dynamic optimization.

The Florida Everglades watershed is widely acclaimed as one of the world's most productive wetland/estuarine ecosystems. However, decades of land and water development have seriously degraded native wildlife communities and threaten the long term sustainability of local economies dependent on tourism, fishing, and adequate freshwater supplies. A major restoration effort is now underway to restore the integrity of natural systems by recreating, to the extent practicable, essential functions of the pre-development regional hydrology. Central to hydrologic restoration is the need to retain wet-season water flows in the northern watershed, much of which are now diverted to sea, to meet dry-season water demands for environmental, urban, and agricultural purposes.

Considerable attention has focused on the potential for expanded water retention within the Everglades Agricultural Area (EAA), reflecting its location between the northern watershed and the Everglades marsh. Agricultural development in the EAA—involving extensive wetland conversion, irrigation/drainage development, and flow-regime modification—has substantially restricted the capacity to retain wet-season runoff in the northern Everglades region. However, measures to increase water retention could impact agricultural industries in the EAA, which is an important production region accounting for $1.5 billion in annual sales. Significant reductions in the scale and profitability of agricultural production may lessen the viability of the sector, reducing direct and secondary benefits from agricultural activity while increasing the potential for land conversion to less environmentally benign nonfarm uses. The challenge for policy makers is to achieve ecosystem restoration goals for water storage while minimizing costs to agriculture and other sectors of the regional economy.

This paper presents an analysis of trade-offs in economic returns to EAA agriculture under alternative water-retention targets for ecosystem restoration. A dynamic model is developed that incorporates key linkages between economic and physical systems, including agricultural production, soil loss, and water retention. Policy scenarios are defined based on water-retention strategies under consideration, including groundwater retention and surface-water storage development. The paper summarizes the effect of water-retention scenarios on production, returns, and resource use in agriculture, and

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comments on the capacity and cost efficiency of alternative strategies to achieve restoration goals.

Water Retention in the EAA

The U.S. Army Corps of Engineers (USACE), in cooperation with the South Florida Water Management District (SFWMD), recently directed a major Reconnaissance Study (Restudy) of the regional water-control system, known as the Central and South Florida Project (C&SFP). The objective of the Restudy was to identify operational and structural modifications that can restore essential functions of natural systems, while maintaining or enhancing other authorized project purposes where possible (USACE and SFWMD). The Restudy was initially authorized under the Water Resources Development Act (WRDA) of 1992 and extended under WRDA 1996. A Comprehensive Everglades Restoration Plan (Comprehensive Plan) was developed and submitted to Congress on July 1, 1999. The proposed Plan is to be constructed over a twenty-year period, at an estimated cost of $7.8 billion (roughly $400 million annually) to be shared equally by the State of Florida and the Federal government.

The capture and storage of excess wet-season discharges from the northern Everglades watershed is an important priority under the Comprehensive Plan. Expanded water retention in the northern watershed is essential for reducing reliance on Lake Okeechobee water storage, minimizing excessive floodwater discharges to the Everglades and east/west coastal estuaries, and increasing dry-season water flows to the Everglades marsh and Florida Bay. A significant share of water discharged annually from the northern watershed, estimated at roughly 1.5 million acre-feet (maf) on average (NAS, p. A-3)[1], could be retained for environmental, agricultural, and urban uses. Increased water retention on EAA lands would be achieved through a combination of onfarm management measures and cropland acquisition for surface-water storage.

Water-Table Management

Proper management of cropland water tables is an important objective of the South Florida restoration program. Cultivation of EAA soils requires frequent adjustments in shallow water tables through a system of onfarm canal/ditches and pumps for drainage and subirrigation purposes. The lowering of natural water tables on drained croplands has accelerated oxidation and decomposition of organic peat soils, resulting in widescale land-elevation declines due to soil subsidence. Soil subsidence is a serious concern in the EAA, resulting in loss of water retention capacity, reduced hydraulic gradients, release of soil nutrients in drainage flows, and productivity loss/increased costs for agriculture.[2] Improved management regimes call for higher average water tables and reduced water-table fluctuations, thus increasing water-storage and water-quality benefits while extending the economic life of soils in agricultural production. However, additional management and structural costs are generally required to control water tables and minimize the risk of yield loss.[3]

Changes in cropping patterns and crop varieties may help to integrate agricultural production with natural hydrologic regimes. The production of rice, which is currently grown in rotation with sugarcane on a limited acreage in the EAA, has been recommended as a cost-effective means of controlling soil loss. Researchers are evaluating existing sugarcane cultivars and developing new varieties with greater flood tolerance that may be economically viable in the EAA (Glaz). Adoption of modified cropping patterns will depend on economic viability in large-scale production, compensation incentives, and water-quality effects.

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[1] This includes discharges from the EAA as well as Lake Okeechobee discharges through the Caloosahatchee and St. Lucie estuaries.

[2] EAA soils are predominantly peat soils composed largely of decayed plant matter, with low mineral content. Loss of organic soil depth in the EAA is attributable primarily to biochemical oxidization. Other factors include soil shrinkage, compaction, burning, and erosion.

[3] The maintenance of higher water tables is an approved management practice under the SFWMD permitting process for water-retention and phosphorus control. Recommended practices include soil-moisture monitoring, timing of irrigation and drainage pumping based on anticipated rainfall events, canal/ditch management, including installation of culvert/canal raiser controls to manipulate water depth, and fallow-field flooding. Water tables can be monitored onsite, through direct soil-moisture monitoring, and offsite, through analysis of stormwater runoff.

Surface-Water Retention

Land acquisition for water-retention purposes has been identified as a high priority activity under the South Florida Restoration Program (SFERTF, Section 5). Primary land acquisition needs in the EAA involve reservoir-storage development, Stormwater Treatment Areas (STAs) or constructed wetlands to filter nutrient-laden drainage flows, and flood-retention areas to contain wet-season flood surges. Surface-water retention facilities can provide for larger volumes of stored water and potential benefits to habitat, recreation, and water quality, although at a cost of reduced scale of agricultural production and substantial public outlays for land acquisition and water-control infrastructure. The Restudy addressed land acquisition needs for EAA water retention, with a primary focus on reservoir-storage development. The Comprehensive Plan calls for approximately 60,000 acres for reservoir storage and flood retention purposes, in addition to 40,000 acres targeted for STA development under the 1994 Everglades Forever Act. The Federal Agriculture Improvement and Reform (FAIR) Act of 1996 allocated \$200 million to South Florida restoration, of which a large share was dedicated to EAA land acquisition for surface-water storage. Congress will be asked to authorize initial funding under WRDA 2000 to begin implementation of the Comprehensive Plan, with surface-water development as a project priority. The State of Florida will address funding for the State share during the 2000 legislative session.

Benefit Trade-offs between Agriculture and Ecosystem Services: A Conceptual Framework

A stylized model of cropland water retention in the EAA is presented to illustrate trade-offs that arise in addressing the dual goals of (*a*) maintaining an economically viable agricultural sector and (*b*) restoring environmental quality to sustain a healthy ecosystem. Two cases are used to emphasize how economic and environmental outcomes will depend on objectives defined. In the first case, resource use is based on private producer decisions only. In the second case, a joint maximization problem is set up where the two objectives are pursued simultaneously.

Producer Decision Case

First, we consider how agricultural production decisions are made when ecosystem values are not included. Building on models developed by McConnell and by Parks and Kramer, we define an intertemporal model of soil and water management for a firm. For simplicity, we assume a single crop, with production based on a per-acre production function. Let soil depth for a given parcel j at a time t be defined as a stock variable denoted as α_{jt}, where depth is measured from zero at the field surface to the underlying marl/limestone layer. Depth to water table, τ_{jt}, is measured from the field surface to the saturated portion of the soil. Yield y on parcel j in period t is a function of soil depth and water-table management. Profits can be expressed as $\pi_{jt}(\alpha_{jt}, \tau_{jt}) = p.y_{jt}(\alpha_{jt}, \tau_{jt}) - c(\alpha_{jt}, \tau_{jt})$, where p is crop price and c is the cost associated with producing that yield and managing the water table at depth τ.[4]

Soil depth decreases over time due to subsidence on drained croplands. The subsidence rate, denoted $\sigma(\tau_{jt})$, depends on the depth to water table, and can be expressed as $\alpha_{t+1} - \alpha_{t}. = \sigma(\tau_{jt})$. The expected "life" T of the land base will be determined by the initial soil depth, α_{j0}, and the subsidence rate. Private landowners, P, will choose water-table depth, τ^P, to meet the single goal of maximizing profits from agricultural production. That is, water-table depth is managed to maximize a stream of production earnings over time, subject to the change in soil depth. The maximization problem can be written[5]

$$(1)\qquad \underset{\tau_{jt}^P}{\text{Max}}\, v_j(\alpha_j, \tau_{jt}^P) = \int_0^{T(\tau^P)} e^{-rt}\pi(\alpha_{jt}, \tau_{jt}^P)dt \quad \text{s.t. } \dot{\alpha}_j = -\sigma(\tau_{jt}^P),$$

where T is the number of time periods until subsidence renders the land unprofitable for agriculture, r is the discount rate, $\dot{\alpha}_{jt} = -\sigma(\tau_{jt}^P)$ is the state equation representing soil subsidence, and v_j is the present value of net

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[4] The production function $y(\alpha, \tau)$ has the usual properties in α and τ. Note that while α is a necessary input, after reaching a certain threshold the average product is constant and the marginal product is zero.

[5] Subscripts p and c are arguments of the profit and value functions. They are omitted here for notational simplicity.

returns to a parcel of land. The conditions for determining optimal water-table depth are[6]

$$(2)\qquad \frac{\partial \widetilde{H}}{\partial \tau^P} = \frac{\partial \pi}{\partial \tau^P} - \lambda \frac{\partial \sigma}{\partial \tau^P} = 0$$

$$(3)\qquad -\frac{\partial \widetilde{H}}{\partial \alpha} = \dot{\lambda} - r\lambda = -\frac{\partial \pi}{\partial \alpha}.$$

Optimal water-table depth is described by equation (2). Optimality requires that the water-table depth be set such that the marginal producer benefit derived from a lower water table equals profits foregone (λ) due to soil subsidence.[7] Equation (3) indicates that the loss in foregone profits grows at the rate of discount less the marginal benefit of soil depth. Solving the maximization problem produces the water table and soil-loss rate by parcel that yields the maximum present value of net returns $v(\cdot)$.

Groundwater retention for a given parcel j is a function of the saturated soil profile (difference between soil depth and depth to water table), and is expressed as $w_{jt} = w(\alpha_{jt}, \tau_{jt})$.[8] Since soil depth changes over time due to subsidence, the time profile of water-retention capacity at any site is characterized as an intertemporal relationship,

$$(4)\qquad w_j = \int_0^T w(\alpha, \tau)dt \quad \text{s.t. } \dot{\alpha} = -\sigma(\tau).$$

Again, in the single-objective case of maximizing production returns, τ^P is chosen by the firm and as such is exogenous to the water-retention problem above. Total cropland water retention is arrived at by integrating $w_j(\alpha, \tau)$ over the distribution, $g(\alpha)$, of soil depths across the EAA, expressed as

$$(5)\qquad W_t = \int_0^{\alpha_t} w(\alpha, \tau)g(\alpha)d\alpha,$$

where $\bar{\alpha}$ is the maximum soil depth.

The case discussed here focuses on the single objective of agricultural profit maximization. A polar case could be defined in which regional resource managers R pursue a single objective of maximizing water retention on EAA lands. In the extreme, maximum water volumes would be retained through removal of agricultural activities, saturation of the soil profile (setting $\tau^R = 0$), and expanded surface-water impoundments. However, this clearly does not consider existing property rights nor beneficial economic uses of EAA resources in agricultural production. More realistic is an intermediate case where land and water resources are allocated for both agriculture and water retention.

Joint Maximization of Agricultural and Environmental Benefits

A stylized joint-maximization problem is defined in which a central planner (regional authority) seeks to jointly maximize two important objectives: agricultural net returns, π, and retained water, W. In the simplest case involving groundwater retention on cropland (i.e., when land acquisition for surface-water development is not considered), the central planner maximizes a benefit function, B, through the choice of the socially optimal water-table depth, τ^S, that maximizes the combined return to agricultural production and water retention. The joint maximization problem is expressed as

$$(6)\qquad \underset{\tau^S}{\text{Max}} = \int_0^T e^{-rt} B\{\pi(\alpha, \tau^S), W(\alpha, \tau^S)\}dt \quad \text{s.t. } \dot{\alpha} = -\sigma(\tau^S).$$

The conditions for choosing the jointly optimized water table, τ^S, are

$$(7)\qquad \frac{\partial \widetilde{H}}{\partial \tau^S} = \frac{\partial B}{\partial \pi}\frac{\partial \pi}{\partial \tau^S} + \frac{\partial B}{\partial W}\frac{\partial W}{\partial \tau^S} - \mu \frac{\partial \sigma}{\partial \tau^S} = 0$$

$$(8)\qquad -\frac{\partial \widetilde{H}}{\partial \alpha} = \dot{\mu} - r\mu = -\left\{\frac{\partial B}{\partial \pi}\frac{\partial \pi}{\partial \alpha} + \frac{\partial B}{\partial W}\frac{\partial W}{\partial \alpha}\right\}.$$

The first expression in equation (7) represents the direct benefits to agricultural production of increasing the depth of unsaturated soil. The second expression represents the broader ecosystem benefits associated with groundwater retention. In the last expression, μ represents the opportunity

[6] The optimality conditions for this case and the ones to follow are based on current-value Hamiltonians. Time and location subscripts are omitted for notational simplicity.

[7] Although this simple characterization neglects the hydrologic connectivity which makes water-table management by parcel problematic, it illustrates the basic nature of trade-offs.

[8] Actual water stored in cropland soils is assumed to be a constant proportion of the depth of saturated soil. The parameter was not included in this exposition for notational simplicity.

cost to society for losses in long-term agricultural productivity and lost water-storage capacity due to soil subsidence on drained croplands. The optimal water-table depth is that at which marginal returns to agriculture from lowering the water table are equal to the marginal benefits for the broader ecosystem that would be obtained by increasing groundwater retained.

Comparing single-objective perspectives with that obtained when both agricultural and environmental goals are considered jointly provides insight into relative optimal water-management regimes. The inclusion of both objectives in the joint problem results in higher marginal costs from lowering the water table (increasing τ) relative to the private case, or $\tau^{P^*} > \tau^{S^*}$. However, in the joint-maximization case, the inclusion of agricultural returns increases the benefits of lowering the water table relative to the single-objective resource-management case. Therefore, the water-table depth in the joint case is greater, i.e., $\tau^{S^*} > \tau^{R^*}$. Thus, the ordering of water-table depth optima is $\tau^{P^*} > \tau^{S^*} > \tau^{R^*}$.

Under the South Florida ecosystem restoration program, some reallocation of land and water will be required to achieve restoration goals. However, the inherent trade-off in agricultural benefits for additional ecosystem services remains an empirical question, reflecting uncertainty over societal preferences for ecosystem restoration and physical/biological requirements to meet restoration goals. Thus, the precise demands on agriculture, and the optimal strategies for achieving these demands, have not been determined. In the analysis presented in this paper, we examine a range of EAA water-retention scenarios under consideration and alternative means of achieving water-retention goals.

Model Simulation

The analytic framework used in the study involves a dynamic optimization model of crop production, soil loss, and water retention in the EAA. The model is designed to address the potential costs of expanded water retention to the agricultural sector, measured in terms of foregone agricultural profits.[9]

The objective function for the EAA agricultural sector (or regional authority) is to choose land and water allocations over a given time-horizon such that the present value of net production returns is maximized,

$$(9)\quad \sum_{t}^{T}\sum_{i}^{n}\sum_{m}^{4}\sum_{k}^{4} [p_{i,t}y_{i,m,k,t}(\tau) - c_{i,m,k,t}(y,\tau)](1+r)^{-t},$$

where t is year ($t = 1, 2, \ldots, 15$), I is crop, m is soil, k is yield-belt, p is crop price, y is crop yield, τ is average depth to water table, c is production cost, and r is the discount rate ($r = 4\%$). The model disaggregates the EAA study area into four yield-belts k and four soils m, with cropping activities I defined based on crop rotations for selected yield-belt/soil combinations.[10] All crop prices p are exogenous to the region. The above intertemporal problem is maximized subject to production function relationships, resource and regulatory constraints, and initial conditions.

The primary land constraints are

$$(10)\quad \sum_{i}^{n} L_{i,m,k,t} + \mathrm{LR}_{m,k,t} \le \overline{L}_{m,k},$$

where L is cropland base by yield-belt and soil, and LR is land retirement. The model assumes that lands retired (both publicly acquired and privately held) are permanently removed from production ($\mathrm{LR}_{m,k,t+1} \geq \mathrm{LR}_{m,k,t}$). Initial cropping patterns ($t = 0$) are set at observed levels through a combination of shadow-price adjustments to net returns and selected crop constraints.[11]

[9] This analysis focuses on opportunity costs to the agricultural sector under alternative land allocations and water-management regimes. The analysis does not consider the public costs of land acquisition and capital infrastructure for surface-water development. The analysis does not address regional benefits of expanded water-storage and flood-control benefits with EAA water retention or other related benefits, including habitat and recreation opportunities on newly acquired EAA lands and reduced phosphorus loading from drained croplands. In particular, the analysis does not address the effect on agriculture of a potential increase in the frequency and intensity of future water-supply shortfalls in the absence of expanded EAA water storage. For an examination of this issue, see USACE and SFWMD, Appendix E—Socio-Economics.

[10] Sugarcane is the major crop in the EAA, accounting for roughly 88% of cropped acreage. It is the focus of the endogenous decision variables in this model. Non-sugarcane crops are included primarily to account for aggregate resource use and returns. Factors affecting sugarcane yield include depth of organic soils, water-table regimes, and micro-climatic effects reflecting proximity to Lake Okeechobee (i.e., yield-belts).

[11] The baseline model run was calibrated to reflect acreage allocations in 1993 (year 1) and estimated levels of future land retirement attributable to soil subsidence over a fifteen-year horizon in the absence of land acquisition for surface-water development (Hazen and Sawyer). Shadow values from the baseline model run

Soil depth α is a state variable, and the critical dynamic element of the model. Soil loss SL over time reflects total acres in production, cropping patterns, and water-table regimes. Average depth of cropland soil in year t is computed based on a weighted-average soil depth over crop rotations at the end of the preceding year. Soil depth on retired lands is fixed at that year's level in which the field is removed from production. Dynamic adjustments for soil loss over time are expressed in

$$(11) \quad \alpha_{m,k,t+1} = \alpha_{m,k,t} - \sigma(\tau_{i,m,k,t}).$$

The three dependent variables—yield, water-table management cost, and soil loss—each depend on seasonal average depth to water table τ at the field level, which is the key management variable in the model. Water-table depth, in turn, is bounded by soil depth over time; i.e., $\tau_{i,m,k,t} \leq \alpha_{m,k,t}$.

Water-retention capacity is a static measure of the volume of water that may be retained in a given year at a point in time (high-flow period), based on cropland water-table depths maintained and surface-water development in place. Groundwater retention capacity is computed as a function of soil depth, depth to water table, and water-holding capacity of the soil. Surface-water retention capacity is a function of cropland area retired and land disposition (STAs, reservoir storage, floodwater retention, or idle).[12] While water-retention capacity is a key focus of our analysis of production impacts, it is important to note that this is *not* a hydrologic model. No attempt is made to model the quantity and variability of EAA water inflows, crop-water demands, and water outflows. In particular, water-retention capacity is distinguished from effective "water storage," adjusted for evaporation and percolation losses. Measures of storage efficiency may vary greatly, depending on temporal, spatial, and functional considerations.

Data Specifications

A cropland base of 500,000 acres—out of approximately 700,000 total acres in the EAA—is assumed in the model. Cropland base is apportioned over EAA yield-belts and soils, based on 1993 acreages from Hazen and Sawyer (hereafter referred to as H&S), table 8-7. Land acquisition scenarios reflect a range of proposals for water-retention development under discussion (personal communication, USACE; NAS, p.18). Cropland removed through public land acquisition is computed based on total land acquired net of the share of noncropland (0.125), i.e., canals, roads, etc. (H&S, p. 4-3).

Production activities include seven representative crop rotations: sugarcane/dry fallow, sugarcane/flood fallow, sugarcane/rice, vegetable/dry fallow, vegetable/rice, continuous sod, and continuous pasture.[13] Base crop-acreage shares, production costs, prices, and yields are from H&S. Base production costs for sugarcane reflect 1990 costs of production as reported by USDA and by Alvarez and Schueneman. Base production costs were adjusted to reflect implementation costs for Best Management Practices (BMPs) from H&S, App. A and B. A fixed BMP cost for fertilizer and sediment control was applied to all acreage. Water-table management costs were specified as a function of water-table depth. Production costs for non-sugarcane crops were obtained primarily through the Institute of Food and Agricultural Sciences, University of Florida. Production returns represent pre-tax crop revenues above variable and fixed production costs. Returns do not include payments to producers for cost-share agreements or cropland sales. Crop prices for the 1992 production year were assumed to apply over the fifteen-year planning horizon. Returns to sugarcane reflect support levels under current U.S.

(years 1–15) were incorporated into the objective function for scenario runs to approximate baseline crop allocations over time with only limited use of constraints, based on procedures developed in Howitt. This model specification was used to evaluate policy impacts in the scenario analysis. Upper bounds on sod and pasture acreage were included to improve stability. Our analysis focuses primarily on changes in sugarcane acreage and resulting resource effects under alternative water-retention scenarios; a thorough analysis of crop substitution opportunities was limited by insufficient water-management and yield-response data for non-sugarcane crops.

[12] EAA water volumes not accounted for in our measure of retention capacity include onfarm water retained "off-field" (ditches and retention ponds and noncropland groundwater), off-farm conveyance/drainage canals, and water retained in EAA wildlife management areas (the Rothenberg and Holey Lands tracts).

[13] Acreage by crop is computed from rotation acres, based on the percentage of months that a given crop occupies the field. Sugarcane rotations assume one plant-crop and two ratoons. Vegetables represent a composite of primary vegetable crops—lettuce, celery, and sweet corn—weighted by relative crop acreage. The study does not assess the range of future production enterprises that may be helpful in retaining soil and water resources.

import restrictions and commodity loan rates for sugar.[14] Sugarcane yields reflect "base" yields by yield-belt (H&S, App. A), adjusted by a quadratic yield-loss function fitted from estimated yield responses under alternative water-table depths (Izuno, p. 131).[15] Sugarcane harvest costs are expressed as a linear function of yield, derived from H&S, table 4-9. Yields and harvest costs for non-sugarcane crops are assumed fixed and constant under all scenarios.

Soil subsidence is computed as a linear function of average depth to water table (Izuno, p. 108). Initial soil depth by soil type reflects reported depth ranges in Snyder (p. 31), and representative levels from H&S. Water-table depths for sugarcane (endogenous/variable) and non-sugarcane crops (fixed/constant) reflect judgment estimates derived from various field studies (Bottcher and Izuno, H&S). Water-table management costs for sugarcane production are based on a quadratic cost function fitted from data in H&S, App. A. Costs range from about \$10/ac to \$75/ac, reflecting additional management and pumping with restricted water tables, and related canal structural modifications with shallow soils. Groundwater retention capacity is based on an assumed linear relationship with depth of saturated soil profile—1 inch water per 7 inches soil (personal communication, SFWMD; Izuno, p. 107). Surface-water retention capacity reflects preliminary engineering design specifications for STAs (2 ac-ft/ac), reservoir storage (6 ac-ft/ac), and floodwater retention (2 ac-ft/ac) areas considered under the Restudy (NAS, p. A-3).

[14] Sugarcane price (\$41.00/ton) is based on the price of raw sugar (21.6 cents/lb.—NY#14 contract price) and by-products purchased by refineries, less production costs (growers) less processing costs (mills) (H&S, p. 4-17). The domestic raw sugar price has remained stable over recent years. Sugar recovery rate per ton of cane sugar is assumed constant over the model time horizon, although recovery rates have generally increased over time (H&S, p. 4-20). For independent growers not affiliated with a milling operation (accounting for about 10% of EAA production), this represents the "maximum price" that could be negotiated with the mills.

[15] Base sugarcane yields by yield-belt range from 28 tons (YB1-2) to 21 tons (YB5). Primary land-quality determinants of yield include depth of organic soil and proximity to Lake Okeechobee. In general, yields are greatest in the northern EAA due to micro-climatic lake effects and deepest soils. Yields decline further south and east, reflecting diminished lake effects and shallower soils that restrict water-table regimes. Base yields, corresponding to an average water-table depth of 26 inches or greater, are assumed to decline by about 2% for a water-table depth of 20 inches and 10% for a depth of 10 inches, assuming that increased water-table management costs are sustained.

Scenario Analysis

The equation system defines an intertemporal multicrop profit maximization problem. The system is solved first for the fifteen-year "baseline" condition, reflecting relative prices, initial crop/technologies, and initial resource endowments from 1990–93 base data. Three sets of policy scenarios are then defined and compared against the baseline: (*a*) cropland water-table restrictions, (*b*) cropland acquisition for surface-water storage, and (*c*) water-retention targets (table 1). The potential effect of sugar price adjustments on water-retention capacity is briefly addressed.

Cropland water-table restrictions under scenarios I-1 through I-5 involve successively more stringent limits on average depth to water table in sugarcane production (assuming no land acquisition). Water-table depths evaluated include 24, 21, 18, 15, and 12 inches, measured from the soil surface. Land acquisition scenarios—II-1 through II-9—involve incremental increases in cropland removed from production (with depth to water table endogenously derived). The model is free to allocate EAA land retirement to minimize agricultural production losses, as the precise siting and design of water-retention facilities have not been finalized. Scenario II-1 involves land acquisition for the STA area only (43,000 acres). Scenarios II-2 through II-5 involve land acquisition for STAs plus reservoir storage and (limited) flood retention. Scenarios II-6 through II-9 include STAs plus expanded acreages for reservoir storage and flood retention, as outlined by the National Audubon Society (NAS, p.18).[16] Finally, scenarios III-1 through III-8 fix water-retention capacity at alternative target levels. Under these scenarios, the model selects the mix of water-table depth and cropland retirement that minimizes profit losses for a given volume of water retention.[17] EAA water-retention targets evaluated range from 100,000 af to 800,000 af, in increments of 100,000 af.

[16] For purposes of analysis, all land acquisition is assumed to occur in $t = 1$, although capital construction for water-storage and retention facilities is likely to be phased in over time. The National Audubon Society suggests that additional flood-retention lands could be acquired from agriculture as land comes available (NAS).

[17] In achieving the targeted water volumes, it is assumed that STA acreage (43,500 acres) is retired first, followed by reservoir-storage lands (up to 75,000 acres) and flood-retention lands (up to 75,000 acres).

Table 1. EAA Water-Retention Scenarios—Agricultural Income Loss and Water-Retention Capacity

	PV-Income Loss (and Percent Change) from Baseline		Water-Retention Capacity ($t = 15$)	Cost per AF Water Retention ($t = 15$)
Scenario Description	$mill	Percent	1000 Acre-Feet (Baseline: 46)	$ / Acre-Foot
I. *Water-Table Restrictions*				
1. 24 inches	15.0	1.4	52	288
2. 21 inches	56.1	5.2	67	837
3. 18 inches	64.5	6.0	81	796
4. 15 inches	79.2	7.3	90	880
5. 12 inches	164.0	15.1	101	1624
II. *Land Acquisition (Acres)*				
1. STA (43,500)	13.7	1.3	139	99
2. STA + RS (25,000)	15.8	1.5	292	54
3. STA + RS (40,000)	50.0	4.6	395	127
4. STA + RS (50,000)	65.9	6.1	442	149
5. STA + RS (50,000) + FR (10,000)	81.4	7.5	464	175
6. STA + RS (75,000)	104.1	9.6	598	174
7. STA + RS (75,000) + FR (25,000)	141.3	13.0	654	216
8. STA + RS (75,000) + FR (50,000)	180.2	16.6	710	254
9. STA + RS (75,000) + FR (75,000)	225.3	20.8	770	293
III. *Water-Retention Targets*				
1. 100,000 ac-ft	1.5	.1	100	15
2. 200,000 ac-ft	12.6	1.2	200	63
3. 300,000 ac-ft	17.8	1.6	300	65
4. 400,000 ac-ft	39.9	3.7	400	100
5. 500,000 ac-ft	57.2	5.3	500	114
6. 600,000 ac-ft	97.5	9.0	600	163
7. 700,000 ac-ft	145.5	13.4	700	208
8. 800,000 ac-ft	240.5	22.2	800	301

Note: STA—stormwater treatment area, RS—reservoir storage area, FR—floodwater retention area

Scenario II-5, with STAs plus 60,000 acres for reservoir storage and flood retention, corresponds roughly with EAA land acquisition needs identified under the Comprehensive Plan. Six STAs are soon to be operational along the south/eastern tier of the EAA. A 50,000-acre reservoir-storage system is currently proposed for a contiguous area of the southern EAA, comprising lands acquired through purchase of the Talisman property ($135 million) and other lands obtained through a series of land swaps. However, the timing and ultimate extent of cropland conversion remains uncertain due to funding contingencies, potential for agricultural lease and land trading agreements, ongoing evaluation of reservoir design specifications, a federal request for 245,000 af of additional water allocations for Everglades restoration above levels addressed in the Comprehensive Plan, the source of which is as yet undetermined, and continued calls by the environmental community for expanded EAA water retention.

Baseline Scenario

Under the baseline scenario, declining productivity due to soil subsidence results in cropland acreage loss of about 10% over the fifteen-year time horizon. Acreage declines from 500,000 ($t = 0$) to 475,000 acres in $t = 9$ and 449,000 acres in $t = 15$.[18] All retired acreage is removed from the least productive lands in the EAA (shallows soils, southernmost yield-belts). Land retirement draws primarily from sugarcane acreage, which

[18] Hazen and Sawyer estimate a reduction in EAA cropland of 80,000 acres over a twenty-year period due to insufficient organic soil (H&S, p. ES-5).

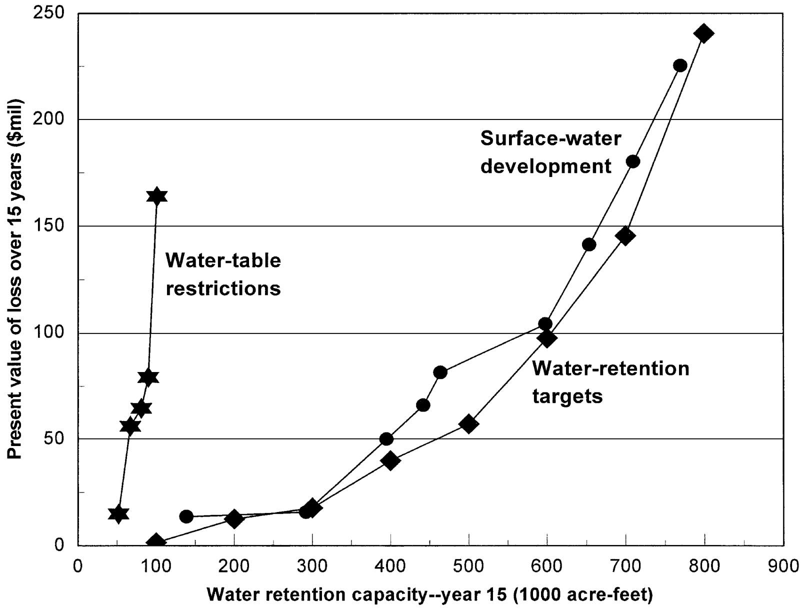

Figure 1. Agricultural income losses by volume of water retention, Everglades Agricultural Area

declines from 374,000 to 337,000 acres over the period.

Soil depth falls across the study area over the fifteen-year baseline, with greatest loss rates occurring on deepest soils within the northern yield-belts. Subsidence rates are less on shallow soils due to high water tables.[19] Average annual soil loss per cropped acre declines from 1.04 inches in $t = 1$ to 0.88 inches in $t = 15$. Water-table depths for sugarcane production vary depending on yield-belt and soil. Water tables were near constant (at or near yield-maximizing levels) for the most productive lands, but declined steadily on croplands with shallow soils. Restricted water tables on shallower soils result in reduced sugarcane yields and markedly increased management costs.

Water-retention capacity declines gradually over time—from 100,000 af in $t = 1$ to 46,000 af in $t = 15$—reflecting reduced groundwater retention capacity due to soil subsidence. There is no surface-water storage under the baseline, since it is assumed that privately held (non-acquired) retired lands are not used for surface-water impoundment.

The present value of baseline production returns totaled $1.1 billion over fifteen years. Annual (non-discounted) returns decline from $105.2 million in $t = 1$ to $82.3 million in $t = 15$; average returns per cropped acre fall from $211/ac to $183/ac. Declines in production returns reflect reduced sugarcane yields, higher water-table/subsidence management costs, and cropland loss due to soil subsidence.

Policy Scenarios

Table 1 shows changes in production returns, land use, soil loss rate, water-retention capacity, and cost per acre-foot of retention capacity for the three sets of policy scenarios. Figure 1 illustrates the loss in forgone agricultural income under alternative water-retention strategies and target levels.

Water-Table Restrictions

Restrictions on water-table depth have a comparatively large impact on production returns, particularly under more stringent restrictions. Reductions in the present value of production returns range from $15 million under scenario I-1 (24 inches) to $164 million under scenario I-5 (12 inches). Income losses reflect reduced yields and substantially higher management costs under shallower water-table regimes.

Water-table restrictions were particularly effective in reducing the rate of soil

[19] Average soil depth in the north (YB1-2) fell from 45 to 28 inches in year 15; in contrast, soil depth in the least productive yield-belt (YB5) fell from 26 to 20 inches.

subsidence. Average annual soil loss in $t = 15$ declined from 0.88/inches (baseline) to 0.65 inches under scenario I-3, and 0.56 inches under scenario I-5. The largest soil savings occur on highly productive croplands in the northern yield-belts, since water tables in the southern EAA are already largely constrained by shallow soils. More stringent water-table restrictions helped to extend the economic life of cropland soils, reducing baseline acreage loss by about 64% under scenarios I-4 and I-5.

Water-table restrictions substantially increase groundwater retention on croplands. Groundwater retention ($t = 15$) expands from 46,000 af (baseline) to 101,000 af under scenario I-5. However, potential water savings are small relative to water-retention targets under discussion. Even under the more restrictive water-table regimes, EAA soils simply do not have the physical capacity to retain the volumes of water achievable through surface-water impoundments. Moreover, the opportunity costs of retaining water through water-table restrictions are generally high. Costs per unit-water range from \$288/af under scenario I-1 (24 inches) to over \$1600/af under scenario I-5 (12 inches).[20]

Surface-Water Development

Land acquisition for EAA surface-water development directly impacts acreage available for farm production. The present value of production returns declined by \$13.7 million (1.3%) under scenario II-1, \$65.9 million (6.1%) under scenario II-5 (corresponding to proposed acreage buyouts under the Comprehensive Plan), and \$225.3 million (20.8%) under scenario II-9. However, the percent decline in returns is substantially less than the percent decline in cropland base since land retirement is concentrated on the least productive lands. Net cropland losses with land acquisition are partially offset by baseline acreage losses in later years due to soil subsidence.

Water retention capacity is significantly increased under the land acquisition scenarios. Water retention in $t = 15$ expands from 46,000 af (baseline) to as high as 770,000 af under scenario II-9. Expanded water-retention capacity is attributable primarily to surface-water development. However, groundwater retention also increases since retired lands are inundated and assumed no longer subject to subsidence. While larger land acquisitions enhance water-retention capacity, the costs—in terms of foregone agricultural returns per unit-water—are high relative to smaller land acquisition scenarios. Annual income losses per unit-water retained in $t = 15$ range from \$54/af under scenario II-2 to well over \$200/af for the largest land acquisition scenarios. Higher per-unit retention costs under the largest acreage buyouts reflect (*a*) differences in surface-water retention capacity, i.e., relatively more acreage allocated for flood-retention areas with less capacity than storage reservoirs, and (*b*) removal of more productive lands to satisfy the land acquisition target.

Water Retention Targets

Figure 1 illustrates the upward-sloping cost schedule for alternative EAA water-retention targets. Low target levels have a relatively small impact on returns to agricultural production. Larger targets have a substantially greater impact on the sector, reflecting higher management costs and reduced yields under shallower water tables, removal of more highly productive lands, and increased reliance on flood-retention lands to capture water. Findings suggest that retention of 800,000 maf (scenario III-8)—representing roughly 53% of estimated average annual discharges from the northern watershed—would result in a 22.2% reduction in farm sector returns. A mid-range target of 400,000 maf (scenario III-4) would retain 27% of estimated discharges, but at a substantially lesser cost to agriculture (3.7% reduction in returns). While cropland acquisition for water-retention development is necessary to achieve the magnitude of water volumes under consideration, the optimal sector response does indicate an overall, if modest, shift to shallower cropland water-table depths under higher retention targets.[21]

Considerations in Interpreting Results

Results of the baseline and scenario analyses necessarily reflect limits of study scope

[20] Where initial water tables are very deep (above 24 inches), small adjustments in water tables may generate water savings at a lesser cost to producer returns.

[21] Costs per unit-water retention under scenarios II:1–9 mirror costs under scenarios III:1-8 (figure 1), reflecting both the relative efficiency of land acquisition for surface-water development and the fact that land-acquisition scenarios allow for endogenous (optimal) adjustment in water-table regimes.

and underlying model/data assumptions. Several issues are addressed here as context for reported findings.

The study baseline reflects initial water-table depths prevalent in the 1990–92 base year, prior to mandated BMPs under the Everglades BMP Regulatory Program (SFWMD, p. 5-1). While water management costs are assumed to rise with reduced water-table depths over the fifteen-year baseline, accelerated rates of BMP adoption after 1994 are not fully captured in baseline assumptions. Thus, baseline results may understate progress to date in managing cropland water retention and soil loss, while scenario results may overstate somewhat the actual cost to producers of achieving EAA water-retention goals.

Cropland acquisitions scenarios for EAA reservoir-storage development assume a reservoir depth of 6 feet, based on preliminary engineering specifications in the Restudy. However, ongoing hydrogeologic analysis may indicate that deeper reservoirs are feasible for specific reservoir sites, reducing land acquisition needs for a given volume of water-retention capacity. Thus, foregone production returns reported here may overstate actual costs to the agricultural sector, depending on the depth of reservoirs to be constructed.

Static measures of water-retention capacity were used in this study as a basis for assessing scenario impacts of cropland acquisition and water-table regimes on the farm sector. Examination of water-storage efficiency was beyond the scope of this study, although evaporation and percolation losses in the EAA are an important hydrologic issue. To the extent that water-retention capacity exceeds effective water storage, costs per acre-foot reported in this study understate the costs per unit of actual water stored.

This analysis has not addressed the effect on agriculture of a potential increase in the frequency and intensity of water-supply shortfalls in water-deficit years. Supplemental irrigation needs have generally been sufficient, given adequate levels of rainfall in most years and a water-allocation system favorable to agriculture. However, irrigation restrictions may become an increasingly critical issue as additional demands are placed on the water-supply system and allocation rules are modified. Expansion of EAA water retention has been sought to reduce agriculture's reliance on the regional water system. To the extent that ground- and surface-water storage in the EAA may be used to offset future water-supply shortfalls—thus minimizing production impacts due to yield stress and acreage idling—effective sector losses reported here may be lessened.

Finally, the analysis does not address all costs of surface-water retention development in the EAA. Foregone production returns reported here represent the minimum compensation the public would have to pay for cropland acquisition under a voluntary buyout program; actual payments are generally higher due to land sale transaction costs and negotiating premiums. In addition, the analysis does not consider additional costs of water-control infrastructure, including system design, construction, and management. Thus, producer losses reported in the study understate the full cost of cropland acquisition, and are independent of substantial capital and operational expenditures for reservoir storage.

Sensitivity of Sugar Price Adjustments

Much attention has focused on price support levels for sugarcane, both in the context of U.S. trade liberalization and environmental restoration in South Florida. U.S. sugar prices are supported through a two-tiered system of (*a*) non-recourse loan guarantees under the federal farm legislation, providing an effective price-floor, and (*b*) tariff-rate import quotas that maintain domestic prices above the loan rate, thereby avoiding loan forfeiture. The 1995 farm legislation included various changes in the Sugar Program, although loan rates were maintained at pre-1995 levels. While there are currently no formal proposals before Congress that would substantially alter domestic sugar prices, pressure to liberalize sugar markets at home and abroad will likely persist.

Sugar price adjustments for Florida producers could affect land allocation incentives, with implications for water retention in the EAA. We examined the potential effect on water-retention capacity in the EAA of a 10% and 20% reduction in the domestic price of raw sugar, using simple sensitivity procedures. Our analysis suggests that a 10% reduction could increase EAA water retention capacity by 10,000 acre-feet annually over baseline levels (year 15), attributable primarily to an acceleration of cropland retirement. A 20% reduction increases retention capacity by nearly 80,000 acre-feet annually. However, the present value of agricultural production returns in the EAA declines substantially, by roughly 15% under the 10% price adjustment and more than 40% under the 20% price adjustment. Moreover, sector costs per unit-water retention are very high relative to direct water-retention strategies evaluated in this analysis. Reduced returns to sugar production may be offset somewhat through substitution of other higher-valued crops in the EAA, although potential expansion of these crops may be limited.[22] Long term effects on the viability of the Florida sugar industry would depend on the degree of sugar price adjustments, the extent of future industry cost liabilities and conservation requirements under the Everglades restoration program, ongoing technological advances in sugarcane production and processing to maintain market competitiveness, and success of international efforts to reduce trade distorting practices that could expand markets for U.S. sugar abroad.

Conclusion

While the South Florida economy has diversified in recent decades, agriculture remains an important source of regional income. However, resource competition to meet the needs of environmental restoration and a rapidly expanding urban sector will place increasing demands on agriculture. At the same time, changes in agricultural markets and federal farm programs may alter production incentives and resource use over time. Agriculture will continue to adjust traditional patterns of land and water use, although the precise demands on the sector and the mix of strategies to meet those demands are uncertain.

Restoration policy development will need to consider the economic trade-offs and potential joint benefits associated with agriculture in the EAA. Findings from this study suggest that small increases in EAA water retention can be achieved with minimal losses in agricultural income. Indeed, improved water-management regimes under the ongoing BMP program have sought to capture these benefits. Agricultural returns decline more significantly under increasingly ambitious water-retention targets—reflecting yield adjustments, higher management requirements, and loss of cropland base. Restricted cropland water tables, while potentially useful in controlling soil loss and nutrient loading, are less efficient as a means of retaining water. Expanded surface-water impoundments are needed, together with recommended water-table regimes, to achieve the magnitude of water-retention volumes under discussion. The costs of surface-water development reflect the full public cost of land acquisition—above foregone production returns examined here—as well as capital and operational costs of the water-storage system. The nature and magnitude of agricultural sector impacts will depend on actual water-retention requirements for ecosystem restoration, which have yet to be determined, and levels of compensation provided.

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[22] Expansion in high-valued vegetable production is conditioned by market demand and price volatility. Reduced trade barriers with Mexico under the North American Free Trade Agreement (NAFTA), combined with Mexican investment in production technologies, devaluations of the peso, and weather factors, have increased competition within the winter-vegetable market (Love and Lucier). Water-quality considerations may also be important, as vegetable production typically involves higher chemicals applications relative to sugarcane. Sod production will remain closely tied with future suburban growth in South Florida. Rice, produced on a limited acreage in the EAA, is recognized as a promising component of an improved crop-rotation system for soil management in the EAA (Glaz). However, potential expansion of rice production—currently a "break-even" crop in the EAA—may be limited by regional milling capacity, downward price pressures with increased local production, and water-supply considerations.

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